PHOTOELECTRIC VS. IONIZATION DETECTORS

A REVIEW OF THE LITERATURE

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INTRODUCTION

Note: ***I am writing this paper to educate regulators, fire chiefs, and the general public. As a consequence, I spend some time discussing matters that might seem obvious to some researchers. At the same time, In trying to justify my opinions I often had to resort to technical explanations. I ask all readers of this paper to bear with me, through portions that are either too simple or too complex for their liking.***

It is a common perception that for residential occupancies there is no clear choice among the various types of detectors. The guidelines typically only require that an approved smoke detector be installed, not that a certain type of smoke detector be installed. Typically the logic for such an argument is the following.

> *"Ionization Detectors are generally conceded to be superior to photoelectric detectors in detecting fast, flaming fires characterized by combustion particles in the range of 0.01 to 3 microns. They are also more sensitive to dark or black smoke. However, photoelectric detectors are superior in detecting slow, smoldering fires characterized by particulates in the 0.3 to 10-micron size range, and they are more responsive than ionization detectors to light gray smoke. Because the contents of most buildings contain a variety of combustibles, it is impossible to predict the size of the particulate matter a fire will produce. The fact that different ignition sources have different effects on combustibles further complicates the problem. For example, a lit cigarette will produce a slow, smoldering fire if dropped in a bed or on a sofa, but if it falls on a newspaper or into a wastebasket, the result may be a flaming fire. Given all these variables, it is impossible to come up with hard and fast rules to help determine what type of detector should be used in a given occupancy."*[1]

In contrast to the previous statement, It is my contention that there are hard and fast rules which if developed correctly will indicate that there is a protection advantage among various types of detectors. I agree that it is difficult to predict the type of fire that will occur in residential occupancies. I also agree that based on this criterion alone, it appears that there is no clear choice as to which type of detector should be installed in residential occupancies. However, when additional and relevant criteria are considered, I believe that a clear choice can be made. The criteria that I would like to discuss in this article are:

1) susceptibility to false alarms (which leads to disablement);
2) ability to detect the most common type of fire that occurs while people are sleeping (as opposed to those that occur randomly);
3) ability to detect smoke when remote from the source of the smoke

I believe taking these criteria into account that the detector that provides a protection advantage is the photoelectric detector.

The basis for my opinion is my 20 years experience in the fire service and a review of the pertinent literature. In the mid 1980's the Boston Fire Department experienced a high-rise fire, during which, ionization detectors did not appear to operate satisfactorily. Deputy Chief Jack White, who was the Fire Marshal at the time, commissioned a study of the problem. Gene Cable, the BFD's Fire Protection Engineer Intern, along with Phil Sherman, the Fire Marshal at Yale, produced a paper that faulted the ionization detectors lack of ability to detect "aged smoke" as the problem.' (The problem of "aged smoke" will be explored later in this paper.) In the late 80's, under the direction of Chief White, and Deputy Chief Martin Fisher, who succeeded Chief White as the Fire Marshal, the BFD produced the first "Nuisance Alarm" Ordinance.' The Department's experience with this problem led to investigation into the common sources of nuisance alarms and methods of prevention in Commercial Occupancies. These two events caused the department to become sensitized to the impact that detector technology could have on response to fire and nuisance "signatures."

In the early 90's, while in the position of the Assistant Fire Marshal, I became disturbed by the number of fatal fires that were occurring due to smoke detectors having the battery removed. One fire in particular which bothered me involved five fatalities, The one surviving member told the investigators that the smoke detector battery had been removed due to repeated false alarms from cooking. At the time, I thought the solution, to the nuisance alarm problem, was to relocate the detector. However, in too many instances I found it impossible to accomplish this due the layout and size of the living unit. The investigation and research that was conducted to look at possible solutions to this dilemma led to the conclusion that photoelectric detectors are much less sensitive to nuisance alarms from cooking. This information was incorporated into the Boston Fire Department's public education programs and the plans review process. It was hoped that recommending the use of photoelectric detectors would reduce the "battery removal problem."

The scope of the problem of missing batteries and disabled detectors on a national level is discussed in the NFPA Life Safety Code Handbook Section 21-3.3.1.

> "*NFPA analysis of reported fires indicates that about one-third of smoke detectors installed in homes are inoperative. A study by the IAFC Foundation found that, when detectors are non-operational, the usual reason is dead or missing batteries. Although 85% of U.S. homes had at least one detector in 1989, the percentage of homes with detectors that are now inoperative now exceeds the percentage of homes with no detectors (although far more fires occur in the latter situation). Therefore, maintaining the successful record of smoke detectors in U.S. home depends nearly as much on reducing the problem of dead and missing batteries as it does on promoting their use.*"'

The causes of disabled detectors were investigated by the Consumer Product Safety Commission[s]. Table 1 represents some of the findings. Nuisance alarms from cooking, steam, and cigarette smoke was reported as a problem for 48% of the cases where the power source was missing. Clearly, any solution to the problem of nuisance alarms, particularly from cooking, could substantially reduce the "missing battery" problem.

Table 1:

Types of Problems Reported

Type of Problem	Total Percentage	Power Source	
		Missing or Disconnected	Operational
Alarms to cooking	28	32	14
Alarms continuously when	27	25	43
Alarms too often, unspecified	21	20	21
Alarms to steam/humidity	9	10	-
Alarms to cigarette smoke	4	6	-
Loose wires/loose battery	4	4	-
Battery runs down too often	3	1	7
Test Button/Other parts broken	3	2	7
No sound when tested	3	3	-
Just stopped working	3	3	-
Chirped/Alarmed with new	2	3	7
Can't find correct battery	2	3	-
Alarms to fireplace	2	3	-
Other	18	20	7
(Unweighted Base)'	(83)	(69)	(14)

In attempting to help solve the nuisance alarm problem the BFD wanted to make sure that we were not exacerbating a different problem. We did not want to reduce the nuisance alarm problem at the expense of the ability to detect certain types of "real" fire signatures. This concern led to an investigation of the most common types of fires that occur while people are sleeping, as well as the types of smoke given off by various types of fires. The BFD wanted to see if there were any common scenarios were the ionization detector was the only detector that would provide adequate protection. This investigation caused the department to resurrect the earlier research concerning the impact that smoke "aging" has on the ability of a detector to provide adequate warning for many residential fatal fire scenarios. Once again the conclusion that was reached was that the photoelectric detector possessed certain advantages over the ionization detector, for reasons that will be discussed later.

The seven years of research and experience that went into the development of these conclusions are contained in this paper. Part One of this paper will start by discussing the technological differences between the two detectors and the impact that the differences have on the ability to detect airborne particulates. Part Two will then discuss the most common types of nuisance alarms and the impact that the different technologies have on susceptibility to these nuisance alarms. Part Three will discuss how the difference in technologies can affect the ability to detect smoke from "real fires." Part Four will discuss manufacturers' recommendations, or lack thereof, and their impact on the issue. Part Five will discuss the testing and approval process and the impact on detector selection. Part Six will discuss some counter-arguments, to the hypothesis that photoelectric detectors are better than ionization detectors, as well as provide responses to those counter-arguments.

PART ONE: SMOKE DETECTOR TECHNOLOGY

Ionization Detectors

The ionization principle depends on the fact that even a very weak source of radiation will increase the ability of air to conduct electricity. In these detectors, a small and carefully shielded bit of radioactive material "ionizes" the air in the detector's smoke chamber. As a result, a very weak electrical current flows through that chamber and is sensed by the detector's circuit. However, when tiny particles of smoke drift into the chamber, they reduce that electrical current flow. When enough particles have entered the chamber, the electrical current drops below the - acceptable threshold, and the detector circuit turns on the alarm horn or buzzer.

Smoke particles do not have to be very large to reduce the current flow in the ionization detector's smoke chamber. In fact, they can be invisibly small! Since hot blazing fires tend to produce more smaller smoke particles, and since these float further in the rising hot air from the fire, ionization detectors usually have a slight edge in gaining early warning of open, flaming fires.

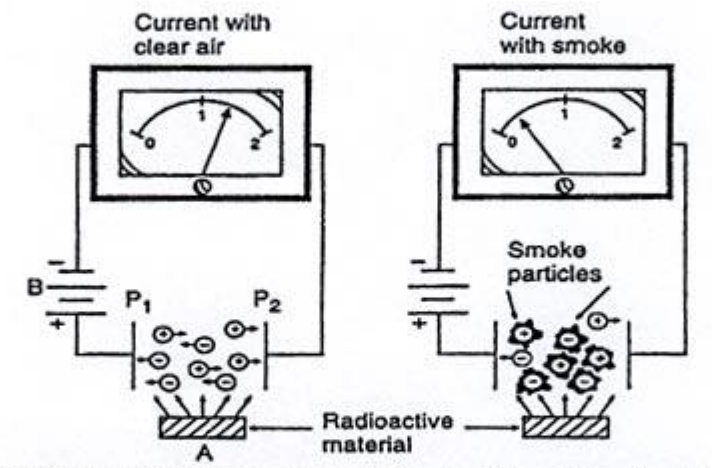

FIGURE 1: Illustration of Ionization Principle[6]

The reason that ionization detectors are more sensitive to small particle smoke is because small particle smoke will typically have more particle per unit volume than large particle smoke and the "ion attachment" is accomplished more easily for small particles. This is explained more fully by Perry Burry as follows.

> "*As smokes are produced they tend to contain a certain mass of particulate matter; initially finely divided, but gradually conglomerating to form larger particles still having the same total mass. As the radius of the particles increase, their volume will increase with the cube of the radius. If the total mass (and hence the total volume) of the smoke particles remain constant, then the number of particles must fall as the inverse cube of the radius. The total effect of the particles is given by the product of their number and their capture coefficient, which is proportional to radius. Hence the total effect is*

proportional to radius times the reciprocal of radius cubed; that is to say the effect is proportional to the reciprocal of the square of the radius. Double the radius of the particles and we only have one quarter of the effect."'

Let me provide the following equations, based on research from Newman', to illustrate this principle.

"The following relationship characterizes the conventional view of the ionization response:

$$y * constant = N_i r_m$$

Where Nt is the total number of smoke particles passing through the ionization chamber and r_m is the characteristic particle size. Y is derived from the change in the ionization current."'

I would now like to utilize this equation to illustrate the phenomena that Perry Burry mentioned in his article. Assume a volume of gas that contains 128 smoke cubes "1 inch" in dimension. The change in the ionization current would be proportional to (128* 1 = 128). Now if one doubles the size of the cube to "2 inches" in width then each "2 inch cube" would contain 8 "1 inch cubes" leaving a total of 16 "2 inch cubes." Now the change in ionization current would be proportional to (16*2= 32). 32 is one quarter of 128. So, by doubling the radius you have one quarter of the effect.

A more recent adjustment to the conventional view has been suggested by Newman, in the same paper referenced previously. He suggests, that to correctly account for the ionization response, one has to take into account "particle charge."

$$y * constant = (1-Xe)\, N_i r_m$$

Where Xe is the fraction of particles charged by the combustion of the material. Newman states that,

"Previous work[9] has measured the fraction of charged particles produced by the combustion of a number of materials, and has shown that particle charge depends strongly on the material burned. For example, flaming wood and heptane were shown to have a charge fraction, Xe, of 0.20, while 0.80 was found for flaming polyurethane. 0.80 was found to be an appropriate value for polystyrene and chlorinated styrene butadiene rubber,"

Newman suggests a modification to the earlier equation to take this charge fraction into account.

$$y = a * 18.62 * N_t * r_m^3$$

In this equation a is the ionization sensitivity factor. Numbers for typical combustibles are provided in Table 2.

TABLE 2: Ionization Detector Sensitivity Factor[s]

Fuel	Flaming	Non-flaming
Douglas Fir	3.07	0.31
Heptane	1.63	-
Coal	1.00	-
Polyvinyl Chloride	0.74	0.89
Styrene Butadiene Rubber/Cl	0.53	-
Polystyrene	0.46	0.50

The consequences of this information, according to Newman are the following.

> *"The sensitivity values listed above, illustrate a reduced dependence of sensitivity on combustion modes as the fuel increases in bond saturation and aromaticity, such that the values for flaming and non-flaming polystyrene are essentially identical (0.46 versus 0.50 * 108). This is an order of magnitude decrease in sensitivity for Douglas Fir from 3.07 to 0.31 * 108, accompanying the transition from flaming to non-flaming wood smoke aerosols. This is supported by the 0.5 to 0.8 equilibrium charge fraction reported for smoke from smoldering wood fire' and is comparable with general ionization detector experience showing insensitivity to non-flaming fire such as from wood."*

This table is important for illustrating the importance that fire type, i.e., fast-flaming or smoldering, has on the sensitivity of the ionization detector. It also illustrates the importance that material type, i.e., plastic or wood, can have on the sensitivity of the ionization detector. It appears that items, such as polystyrene or PVC, can create detection problems for ionization detectors, even in the flaming mode, that are similar to the problems created by smoldering fires where wood is involved. There is also an apparent insensitivity to smoldering fires involving plastics, on the part of ionization detectors. This concern will be addressed later in this paper.

Photoelectric Detectors (Light Scattering)

The operating principle of the photoelectric detector is best explained by a description from the NFPA Life Safety Code Handbook,

> *"Spot type smoke detectors operate on the light scattering principle. A small light source, usually an infrared LED, shines a beam into the detector chamber. A light sensitive receiver is located so that it normally sees only a very small amount of light from the source reflected from the detector chamber. When smoke enters the detector chamber, additional light is scattered within the chamber, some of which reaches the photosensitive receiver and changes the detector signal. As with ionization detectors, the magnitude of the signal is related to the number and size of the smoke particles.*
>
> *There are many other factors that also affect the signal from a light scattering smoke detector. The color of the smoke affects the amount of light that is scattered. Dark smoke such as that from some plastics and hydrocarbon fuels,*

absorbs more light than it reflects, so more light is required before the alarm signal reaches the alarm threshold. Light colored particles reflect a lot of light, so smaller quantities can produce strong signals. Particle shape also affects the amount of light refracted, as does the wavelength of the light source and the angle between the source and receiver. However, in general, in the case of a particular scattering type of photoelectric detector design, the strongest signal is obtained when there are large, light colored smoke particles in the chamber.[s6]

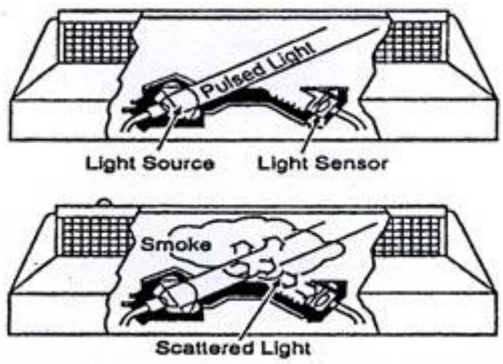

FIGURE 2 Illustration of Photoelectric Principle[6]

The factors that affect the response of a photoelectric detector are more complicated than the factors that affect ionization. The output signal from a scattering type detector optical assembly is affected by particle diameter, complex refractive index, scattering angle, scattering volume, light wavelength, and particle shape. The affect of particle size falls into three regions defined essentially by the ratio of particle size to light wavelength. At a particle diameter less than 0.1 * wavelength it is proportional to the particle diameter to the 6`h power. At a particle greater than 4 * wavelength it is proportional to the particle diameter squared. In the middle region it varies.[10] The important point to take from this information is that the sensitivity of the photoelectric detector does not drop off as much as the ionization detector when the number of particles in the aerosol decreases.

The difference in operational technology between the two detectors is the reason for the ionization detectors higher sensate to fast-flaming fires, which produce small particle smoke. It is this same technological difference that causes ionization detectors to be most sensitive to "invisible smoke" while at the same time light-scattering detectors are virtually insensitive to invisible smoke. It is probably useful at this point to define "invisible smoke".

> *"Light is electromagnetic radiation and is propagated as a wave effect. One of the peculiar features of all wave-propagated phenomena is that they are affected little by things very much smaller than the wavelength of the radiation. In the case of light, the wavelength is about 1.5 microns (a micron is a millionth of a meter), although it varies a little with the color of the light. Smoke particle diameters - can vary between about .001 microns and 1.0 microns, although in typical smokes most of the particles will have diameters between .01 and 1 micron."*[']

Therefore smoke particles that range in size from .001 microns to .1 microns are essentially invisible since they will not affect the ability of light to propagate. Since the photoelectric detector requires that light be scattered it is completely insensitive to invisible smoke. The ionization detector is still sensitive to invisible smoke because of its mode of operation as explained earlier.

A chart which graphically displays the changing sensitivities of photoelectric and ionization detectors over the ranges of smoke color is found in Figure 3. It shows that the photoelectric is more responsive to light smoke, which should be common during the early stages of most structural fires. For extremely dark smoke the ionization detector is more sensitive due to the fact that dark objects absorb rather than reflect or scatter light.

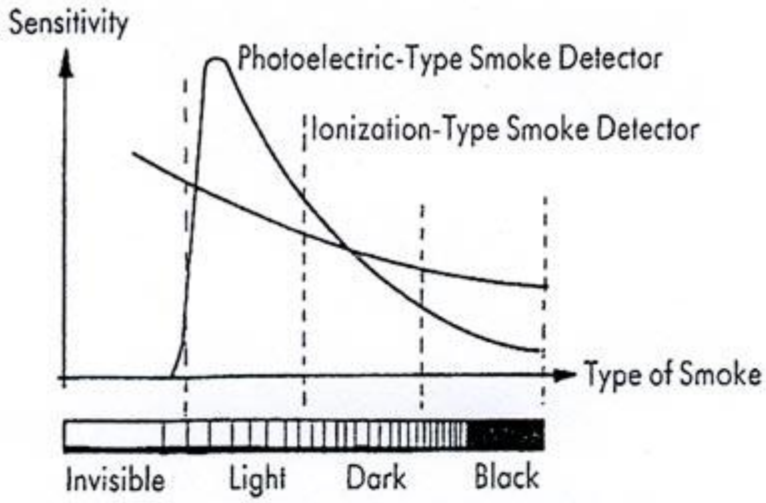

Figure 3: Response Sensitivity of Detectors[1]

A chart which graphically displays the changing sensitivities of photoelectric and ionization detectors over the ranges of particle sizes, for constant mass concentration, is Figure 4. The fact that the total mass of particulates stays constant for a given volume of air cause the number of particles to decrease as the size of the particle increases. It is actually the decrease in the number of particles per unit volume rather than the increase in particle size that cause the decrease in sensitivity as the size increases. In this chart A represents a photoelectric detector with the "scattered light principle, B represents a projected beam detector, and C represents an ionization detector.

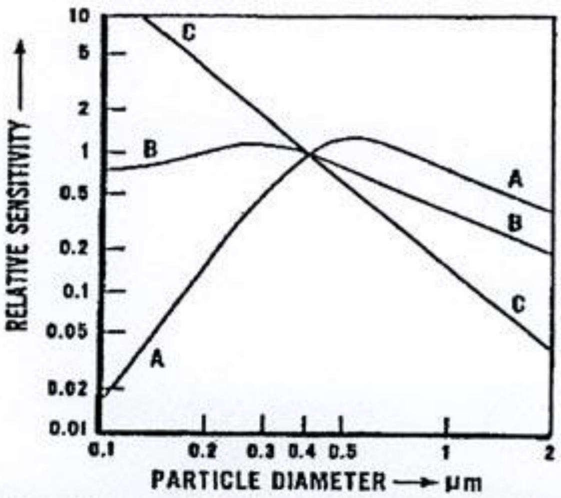

Figure 4: Relative Sensitivities of Three Technologies as a Function of Particle Diameter[11]

1. Both charts are important, in that they illustrate the relative insensitivity of the photoelectric detector to "invisible smoke". If most nuisance alarms fall into this category of "smoke" then the photoelectric detector should in theory experience less nuisance alarms.

2. The particle diameter chart can be used to confirm Perry Burry's statement regarding the ionization detector that, "Double the radius of the particle and we have only one quarter of the effect". At a diameter of 0.2 the relative sensitivity of the ionization detector is approximately 5.0. At a diameter of 0.4 (double 0.2) the relative sensitivity is approximately 1.25 (one quarter of 5.0).

3. The particle diameter chart can be used to illustrate that the photoelectric detector is much more sensitive to the larger particles typical of smoldering fires, than the ionization detector. For a particle diameter of 1.0um the photoelectric, scattering principle is approximately 5 times (0.75/.15) more sensitive. For a particle diameter of 2.0um the photoelectric, scattering principle is approximately 10 times (0.5/.05) more sensitive.

PART TWO: NUISANCE ALARMS IN RESIDENTIAL OCCUPANCIES AND CONSEQUENCES FOR DETECTOR CHOICE

Sources Of Nuisance Alarms in Residential Occupancies

Based upon my experiences with the Boston Fire Department in responding to thousands of nuisance alarms, the majority of nuisance alarms in residential occupancies are caused by cooking, steam, smoking, fireplaces, and insects. It is also my observation that cooking causes more false alarms than all of the others put together.

Although there has not been a tremendous amount of research on this issue, several studies are worth noting. A study conducted in the late 70's in Woodlands, Texas found the following frequencies of unnecessary alarms: Cooking (30.4%). Mechanical/Sensitivity (24.2%, Fireplace (21,6%), Unknown (6.7%), Human Error (4.5%). Heating (3,7%), Power Interrupt (2.6%). Fumes (2.2%), Smoking (1.8%), Insects (1.4%), Other (8%). A further breakdown was done for "Problem Homes" and it was found that in 60% of the problem homes that cooking was the predominant alarm type, in 15% the Fireplace was the predominant cause for alarm, and Malfunction/Sensitivity was the alarm type for 25% of the problem homes".

A more recent study conducted in Maryland in 1984 found the following causes of nuisance alarms: Cooking (72%), Fireplace (7%). Steam (4%). Forced Air (4%), Other (13%). more than one cause (13%). A very recent study conducted on the Devils Lake Sioux Reservation found very similar results: Cooking (76.7%), Steam from bathroom (17.8%), Cigarettes (5.5%), Fireplace/wood stove (4.1%), Chirping (1.4%), Other/Unknown (10.9%).[14]

This was also confirmed by a recent survey conducted by the Consumer Product safety Commission. "All respondents to the survey were asked whether any of their detectors had ever gone off when there was no fire, other than when being tested. Just over half said that they had. By far the most common reason for alarms when there was no fire was cooking, cited by 80 percent of those who reported having such alarms. Low batteries were cited as a reason for nuisance alarms by 20 percent, followed by steam from bathrooms, mentioned by 6 percent. The "alarms" cited by most of those who said that the cause was low batteries probably were "chirps" many detectors are designed to emit when the battery power is low.[s5]

Smoke Particle Size and Color of Most Common Nuisance Alarms

It is important at this point in this discussion to review the literature with regards to the particle size and smoke color of the most common sources of nuisance alarms. Based on information presented earlier the most common sources are cooking, smoking, steam, and fireplaces. The two sources used to find this information in were: Veterans Administration Study['S] and the NFPA 101, The Life Safety Code Handbook[16] .

Cooking and Baking

VA Study - In addition to particulates emitted from cooking and baking operations, this category includes such related causes as making popcorn, toast, etc. *Ion* type detectors are more susceptible to such processes since very little visible smoke is usually emitted.

LSC Handbook - Cooking odors are blamed for a large number of nuisance alarms. The odors that are produced by cooking contain a large number of small invisible particles. An ionization smoke detector would be a probable nuisance alarm in response to cooking odors, while a photoelectric smoke detector would probably not alarm unless the food was well burned and producing visible smoke. Therefore, unless the detector can be located far enough from the kitchen to avoid odors, the better choice is a photoelectric detector.

<u>Smoking</u>

VA Study - Smoking by patients, and sometimes staff and construction workers, is a common problem. Although a false alarm can occur from a single person smoking directly under a detector mounted on an 8 ft. or lower ceiling, this occurs only if the detector sensitivity is fairly high (less than 1 percent per foot - 0.015 optical density per meter). Most false alarms stem from the smoke from two or more persons congregating near a detector. In general, if the sensitivities of an ion and photo detector are equal, the photoelectric will be more sensitive to the visible smoke particles that are generated by cigarette smoking.

On the other hand, the ion detector would be more responsive to the smaller so-called "invisible" particles emitted from the burning end of the cigarette.

LSC Handbook - Cigarette smoke causes nuisance alarms from ionization and photoelectric smoke detectors. When the smoke dissipates to a light cloud, the ionization detector is likely to alarm first. When the smoke is heavy and thick, either type will alarm.

VA Study - Condensed steam, which is viewed by detectors as equivalent to white smoke, originates from several sources:

1) near showers or in lavatories;
2) near kitchen washing facilities;
3) in laundry facilities;
4) from sterilizers, and;
5) from leaks in steam heating pipes located in-mechanical and equipment rooms

LSC Handbook - Steam from showers and large sinks contains lots of small water drops and has much the same effect as cooking odors in causing nuisance alarms from smoke detectors. The heavier the steam, the more likely it is to also cause photoelectric smoke detectors to alarm. Detectors can often be located to avoid these sources of false fire signatures.

<u>Fireplace</u>

Fireplaces as a source of false alarms were not specifically discussed in either the VA study or the LSC Handbook. In the Woodlands, Texas Study ", the example of fireplace as a cause of false alarms that was given was when the damper was closed. It seems that if a nuisance alarm is caused by having a damper closed, then the smoke would progress from small light particles to large dark particles relatively quickly and that either a photoelectric or an ionization detector would alarm relatively quickly. This type of nuisance alarm would be relatively rare in urban settings.

At this point in the paper I have presented information that seems to indicate that the most common sources of nuisance alarms produce the type of smoke that the ionization detector is most sensitive to. If that is true then their should be information in studies which shows this phenomena. I would like to now discuss the data that is available on the subject.

Comparison of Photoelectric and Ionization Regarding Nuisance Alarms

Although there have not been many studies comparing ionization and photoelectric detectors in residential occupancies, information that I have found in several studies which contain portions that appear to have relevance to this issue.

In Woodlands, Texas[12], the high frequency of unnecessary alarms initiated by ionization type detectors caused the authorities to study ionization versus photoelectric. Both types of detectors were placed side by side in certain apartment buildings. Table 2 shows the data from this study.

TABLE 2: Summary of Woodlands Study["]

Type of Alarm	Type of Detector		Total
	Ionization	Photoelectric	
Cooking	78	5	83
Malfunction	26	5	31
Heater	**4**	0	4
Cigarette	1	0	1
A/C Unit	3	0	3
Shower	3	0	3
Human Error	0	1	1
Total	115	11	126

As shown in table two, 90% (115/126) of the total number of false alarms were recorded by the ionization detectors, 86% (83/95) of the non-malfunction alarms were caused by cooking. This study clearly shows that the most common source of false alarms in a residential setting is cooking and that ionization detectors are clearly more susceptible to these types of false alarms. Another study which compared ionization versus photoelectric was conducted in Maryland[13]. Table Three lists the number of homes in the study that experienced 0, 1, 2, or 3 or more alarms. If one defined "problem homes" as those homes experiencing 3 or more false alarms, it would appear that the homes with ionization detectors are three times more likely to become a "problem home" than those homes equipped with photoelectric detectors.

TABLE 3: Summary of Maryland Study[t3]

Detector Type	Number of Alarms Per Home					(3+ Total)
	Total	**(0)**	(1)	(2)	(3+)	
Ionization	500	364	39	18	79	16%
Photoelectric	77	66	2	5	**4**	5%
Combination	**8**	7	1	0	0	0%

This is the same Maryland study, cited earlier in this paper, which found that 72% of the nuisance alarms were from cooking. Once again, the study would appear to support up the thesis that the most common source of false alarms in a residential setting is cooking and that ionization detectors are clearly more susceptible to these types of false alarms.

A recent article by Consumer Reports appears to support these earlier findings that ionization detectors are more susceptibility to nuisance alarms from typical cooking smoke. The test consisted of mounting the detectors 7 feet above the skillet and oven and the cooking consisted of grilling hamburgers on a skillet and making dark toast in a toaster oven. 6 of the 19 ionization detectors tested repeatedly experienced cooking false alarms. None of the 3 photoelectric detectors experienced this problem.["]

In the study that took place in the Native American Community[14] there were not a lot of photoelectric detectors used. To quote from the study,

> *"There were only three photoelectric detectors in our survey, none of which had nuisance alarms. One trailer had two of these detectors, each of which was paired with an ionization detector that was installed within 6 inches of it. Both of the ionization detectors sounded cooking nuisance alarms. In another home, the photoelectric detector was located 6 feet closer to the* stove than an ionization detector, which had frequent alarms from cooking."

As a consequence of these types of observations the researchers concluded that,

> *"... We favor photoelectric detectors to reduce rates of nuisance alarms from cooking and to provide optimal protection from cigarette related fires. Electrical detectors with battery back-up are the detectors of choice, except in communities such as remote villages in Alaska, where alternating current is non-existent or unreliable. If ionization detectors are installed, they should be located at least 20 feet, and preferably 25 feet, from stoves and at least 10 feet from bathroom doors if possible."*

This logic which has been part of the Boston Fire Department's Plans Approval procedure since the early 90's, was submitted, in late 1995 to the Committee that was helping to write the latest update of the Massachusetts State Building Code. This was the first opportunity to submit this proposal since the policy was adopted by the BFD. (The Building Code, which is updated every five years by law, had last been updated in 1990.) As a consequence of this proposal, the Massachusetts Board of Building Regulations and Standards recently voted the following language into the Massachusetts State Building Code.'[8]

> "Section 919.3 - Where required: single and multiple station smoke detectors or household fire warning systems shall be installed and maintained in full operating condition in the locations described in 780 CMR 919.3.1 through 919.3.3. Any smoke detector located within 20 feet of a kitchen or within 20 feet of a bathroom containing a tub or shower shall be a photo electric type smoke detector."

As stated earlier, the Massachusetts Board of Building Regulations and did not want to reduce the nuisance alarm problem at the expense the ability to detect certain types of "real" fire signatures. The next part of this paper will deal with this issue.

PART THREE: ACTUAL FIRES TYPES IN RESIDENTIAL OCCUPANCIES AND CONSEQUENCES FOR DETECTOR CHOICE

Smoldering Fires

Some people seem to feel that given the various types of fire loads and ignition scenarios that might be present it is impossible to predict ahead of time that type of fire will take place, and therefore impossible to predict which type of detector is better suited for a given situation. However, I would argue that the main function of a smoke detector is to alert a sleeping occupant. NFPA 72 Section A-2-5.2.1 appears to agree with this. "The major threat from fire in a family living unit occurs when everyone is asleep.[s19] Based on this assumption, I believe that it is possible to predict the most common type of fire that kills people who are sleeping.

I believe that the type of fire that kills most people at night is the type of fire that starts out as a smoldering fire. Several studies support this position. According to "Fire In The United States 1983-1990" fire deaths tend to peak late at night and in the early morning hours, such as when fires caused by dropped smoking materials have been smoldering for several hours and then rapidly increase in smoke production and open flames.[i20] In a 1979 study of fatal fires, the NFPA found that, "two-thirds of the deaths in one and two fatality fires resulted from fires reported to the fire service between the hours of 8pm and 8 am. Moreover, most of these deaths occurred in fire that gained large head starts - over 40 minutes for 38% of such deaths - before discovery.[i21] Another study which seems to indicate that it is the smoldering fire that we should be concerned with detecting was a British Study.[22,23]

> *"The data broke the fire into two types. Fires estimated to have been discovered within 5 minutes of ignition (most likely to have been rapidly growing flaming fires) and for fires where the time to discovery is estimated to have been 30 minutes or more (most likely to have involved a period of prolonged smoldering before severe flaming). The preliminary data show that there were 23,082 fires in the first category, but only 4 fatalities, while for the second category there were fewer fires (5,870) but 20 fatalities, a ratio per fire of 1:20. Obviously, a number of interpretations could be put on this data, but it does seem that people in this active age group are able to escape from rapidly growing fires in domestic-sized compartments. Fatalities are much more likely in fires that have undergone a period of prolonged smoldering, when victims may have been overcome by prolonged, low level exposure to narcotic fumes. If this is the case, perhaps there should be more concern about the ability of materials to continue smoldering, with toxic gas buildup over a long period of time, at least in the context of this class of fire."*

Although fast flaming fires can occur while people are sleeping it appears that the odds are more likely that it will start as a smoldering fire. This makes sense when one takes into account that most ignition sources, which lead to fast-flaming fires, involve people. It is difficult to imagine a majority of fast flaming scenarios where the person could start the fire and then fall asleep so fast that they needed the smoke detector to alert them to the fire. Conversely the smoldering, slow growth, fire is by nature, the type of fire which gives people plenty of time to fall asleep before the hazard develops. Since the photoelectric detector is better at detecting smoldering fires, isn't that another reason, in addition to the reduced sensitivity to the most common sources of nuisance alarms, to favor photoelectric detectors.

The reason that photoelectric detectors are better at detecting smoldering fires appears to be due to the fact that smoldering fires produce "large" particles. As illustrated earlier in Figure 1, the sensitivity of ionization detector decreases as particle size increases. (Assuming constant mass.) What many do not realize is that "fast-flaming" fires can also produce large particles due to "smoke aging". The consequences of this for detector sensitivity will be discussed in the next section.

Aged Smoke and Its Effect on Ionization Detector Response

The problem that "aged smoke" creates for ionization detectors can be summarized as follows.

> *"Examination of smoldering smoke has shown that very likely smoke agglomeration, or small particles sticking together to form larger smoke particles, is taking place very close to the combustion zone due to slow smoke flows. Agglomeration of smoke particles from smaller particles to form large particles is taking place immediately at the combustion zone, more evidence shows that as time proceeds agglomeration continues, though at slower rates.*
>
> *This process of smoke particle agglomeration, whatever the mechanism, is extremely important in relation to the ionization detection principle. If smoke particles have already agglomerated with other smoke particles and become large, and possible neutralized any charge polarities, they would be less prone to attach to an ionized air molecule in an ionization chamber. This process of smoke agglomeration for smoldering smoke is the same process that takes place in smoke aging, as smoke travels a distance from a fire. The demonstrated lack of sensitivity by ion detectors to smoldering smoke should then apply to aged smoke as well, even in cases of large flaming combustion. The agglomeration phenomenon may be simply taking place a farther distance from the fire.*[i2]

In the study quoted above several actual fires are provided as examples. 19

Westchase Hilton Hotel, March 6, 1982 in Houston.'

> *"This fire, documented by an NFPA investigation, describes single station guest room detectors not sounding even though smoke was obvious in the rooms. Interviews with guests gave no indication of detectors activating in the rooms. Some guests were awakened by other means to find their room full of smoke. Some reported dizziness and weakness upon awakening. Some people interviewed were in rooms as close as across the hall from the fire.*
>
> *It is interesting to note that the first fire alarm came from an eighth floor elevator lobby photoelectric detector, four floors away. A guest had propped open the door to her eighth floor room to clear smoke. At this time the source of smoke had not been discovered and the fire room door (4th floor) was closed. The eighth floor room was the first occupied room above the fire."*

Boston. MA Prudential Building. January 2. 1986.[2]

> *A fast growing fire broke out on floor 14 of a 52 story office building in cardboard boxes and polyurethane foam packing materials. The fire grew quickly to involve all*

of the combustibles on the floor, about 13,000 sq. ft. The detection system consisted of photoelectric "in duct" smoke detectors and ceiling mounted ionization detectors at elevator lobbies and electrical closets. A printout giving the exact times of smoke detection on each floor produced a record of detector activation. Alarm horns were designed to sound only on the floor above.

The ionization detectors on floors 43, 44, 45, 48, 49, 50, 51 and 52 never activated during the 2 hour 8 alarm incident. Smoke was known to be "thick" with visibility at less than 10 feet at the upper floor elevator lobbies within 4 minutes. Because of system design fire alarm horns on those floor never activated either. Floor 46 alarmed six minutes into the fire and shut down all HVAC Systems for the top 10 floors, also disabling the sampling type photoelectric duct detectors for the top 10 floors. A Boston Fire Department Inspector checked each detection circuit immediately after the smoke conditions cleared and all detection circuits tested OK.

Note that the velocity of the smoke in the elevator lobbies appeared high as the stack effect spread smoke."

It would seem that photoelectric detectors are not only better at detecting smoldering fires but that they are also better at detecting fast flaming fires that start remote from the detector, due to smoke agglomeration. To repeat a quote from Perry Burry, "For an ionization detector, if you double the radius of the particle we have only one quarter of the 1
effect."' The consequence of this physical effect of smoke agglomeration and reduced sensitivity of an ionization detector to larger particles is that the advantage of photoelectric smoke detectors to smoldering fires is even greater when the detector is not in the same room as the room of origin and the advantage of using ionization detectors to detect fast flaming fire is reduced when the detector is not in the same room as the room of origin.

In my opinion this situation is exacerbated by the fact that most doorways in residential settings have door soffits. Door soffits are important because of the factors that impact on smoke aging. According to Cable and Sherman these factors are:

1. initial size of particles,
2. concentration of particles, and
3. time (velocity of smoke gases)*.

***Note:** The length of time required for smoke to reach the detector rather than the linear distance is not important. Time to reach the detector is effected by the fires' hot gases' driving force (smoke velocity) as well as the linear distance to the detector.

If time is indeed an important factor then the impact that a door soffit, in between the fire and the detector, would have is obvious. The soffit would stop the velocity of the particles along the ceiling and allow the smoke to build up to a depth equal to the distance from the top of the doorway to the ceiling. This should accelerate the smoke aging affect.

Both photoelectric and ionization detectors were placed adjacent to each other in both the room of origin, approximately 6 feet away from the fire and right outside the room of origin approximately 12 feet away from the fire. Both smoldering and fast flaming fire were tested.

Table 4: Summary of Norwegian Study

Detector Location	Smoldering Fire Response (seconds)	
	Photo Electric	Ionization
Smoke Detector in Room of Origin	2,500 - 3,000	5,000 - 5,500
Smoke Detector Outside Room of Origin	7,000 - 8,000	N/A

Detector Location	Flaming Fire Response (seconds)	
	Photo Electric	Ionization
Smoke Detector in Room of Origin	60 - 100	30 - 60
Smoke Detector Outside Room of Origin	170 - 210	220 - 240

Some comments made by the researchers concerning the smoldering fire tests are the following:

> *"In cases of smoldering fires, the critical limits for the accumulated CO-dose and visibility in the test room were reached at the same time. This was typically 5000-6000 seconds after the start of the fire. The optical smoke detectors in the test room detected the smoke sufficiently early to avoid a lethal situation during this type of fire development. The ionization smoke detectors detected smoke from a smoldering fire much later than the optical detectors. When the particular conditions during the fire development are taken into consideration, there are reasons to indicate that this detection principle would not provide adequate safety during this type of fire."*

Some comments made by the researchers concerning the flaming fire tests are the following:

> *"The ionization smoke detectors have the best characteristic for the flaming fires in the room where the fire starts. ... When the door to the room with the fire is closed, cases have been reported when the sequence between the optical and the ionization-based detectors is the reverse of the situation in the fire room. (That is, even for flaming fires the photoelectric responds first - my words.) In general the difference between the alarm times for the optical and the ionization detectors are reduced when detection is made from an adjacent room. This can be related to the fact that particles included in the smoke tend to coagulate (smoke aging)."*

A flaming fire develops so that the critical limit is associated with the temperature in the upper smoke-filled part of the room; this is typically 200-240 seconds after ignition. The ionization detectors have the best characteristics for the flaming fires in the room where the fire starts. The typical times of detection for the ionization smoke detectors and the optical smoke detectors are all under the critical limits related to heat stress. During selective surveillance (i.e. corridor mounted detectors monitors several rooms and the door to the test room is closed), both the ionization smoke detectors and the optical smoke detectors gave alarms before the situation in the room with the fire became critical. However, the evacuation time can only be characterized as marginal. When the door to the room with the fire is closed, cases have been reported when (even for fast flaming fires) the sequence between the optical and the ionization based detectors is reversed.

In general the difference between the alarm times for the optical and the ionization detectors are reduced when the detection is made from an adjacent room. This can be related to the fact that particles in the smoke tend to coagulate (smoke aging).

Factory Mutual Study(1988)[25]

Twelve fire tests were conducted in a simulated hotel guestroom and corridor to evaluate the performance of extended coverage horizontal sidewall sprinklers equipped with fast-response lines and the performance of light scattering and ionization smoke detectors. Eight of the tests were flaming-started fire tests in which ignition occurred by electric match in a metal waste-paper basket. The remaining four tests were smoldering-started fire tests in which smoldering was initiated in a bed with an immersion heater placed under the sheets. Four different ventilation conditions were used: (1) guest room and corridor ventilated with guest room door open; (2) the same *conditions* as (1) with door closed; guest room unventilated and corridor ventilated with guest room door open: and (4) that same conditions as (3) with the door closed.

Table 5: Factory Mutual Study

FM Smoke Detector Tests Response					
		Detector In Room		Detector Out Of Room	
Description of Fire	Test Number`	Photo Electric	Ionization	Photo Electric	Ionization
Flaming Fire - Chair'	1	55 - 180	36 - 53	247 - 255	238 - 250
	3	85 - 182	32 - 42	221 - 249	222 - 231
Flaming Fire - Bed'	5	27 - 88	28 - 38	160 - 176	143 - 144
	7	53 - 61	22 - 34	108 - 193	106 - 195
Smoldering Fir&'	9	22 - 28	52 - 53	53 - 54	53 - 54
	11	4- 17	12-20	53-54	53-54

a Response Times are in seconds.
b Response times are in minutes. After a long period of smoldering a fast fire was artificially started by the testers.
c The even numbered test were conducted with the door to the hallway closed. In these cases the sprinkler usually operated before the detector in the hallway.

Other studies have compared the response of ionization vs. photoelectric. One was conducted in Ft Lauderdale in 1984[26]. Some of the conclusions were as follows:

> *"1) The photoelectric smoke detector operated an average of 13.2 seconds after the ionization detectors in the flaming-started fires, 2) The photoelectric smoke detectors operated first in the smoldering-started fires, and 3) The photoelectric smoke detector operated 1 hour and 8 minutes, 29 seconds before the first ionization detector in the smoldering-started fire. In this test, all photoelectric detectors in the room, as well as the photoelectric detectors in the corridor beyond the closed door, responded before the first ionization detector."*

It would appear that the only type of fire scenario where the ionization detector is superior to the photoelectric detector is for a fast flaming fire where the smoke detector is located in the room of origin. Even here the studies indicated that the photoelectric, although slightly slower in response is still adequate. For fast flaming fires where the detector is located outside the room of origin the response advantage of the ionization over the photoelectric appears minimal, and if the door is closed non-existent. For smoldering fires the photoelectric detector is better in all cases.

These more recent studies: Sweden[24], Factory Mutua1[25], and Ft. lauderdale[26] seem to contradict some famous studies done during the mid-seventies such as Indiana Dunes[2] and Heckestad[29]. These studies did not find an advantage of one detector over another. It is important to point out that the testing at Indiana Dunes appears to have been relied upon when the U.L. Standard for Smoke Detectors, UL 217[30], was developed, as well as the "one detector per level" recommendation. However, it is interesting to point out that detector technology has changed since these studies were conducted, which may explain the differing conclusions. This may mean that the results from tests conducted in the mid-seventies do not have the same relevance today that they did then.

An example of the type of technological change that may explain the differing conclusion is highlighted in Heskestad's paper[29]. In this paper Heskestad's states,

"The ionization detector performed adequately in the protectable flaming fire starts, and, in general, inadequately everywhere in the smoldering fire starts. The poor performance in the smoldering fire starts is believed to be intrinsic to the detectors generic class. The photoelectric smoke detector did not perform adequately anywhere in the protectable flaming fire starts, but was adequate almost everywhere in the apartment, in the smoldering starts of long duration. Inadequate performance in the protectable flaming starts and the smoldering starts of shorter duration was judges to be the effect of large characteristic length L, a property of geometric design."

On the surface this statement appears to reinforce the statement at the beginning of this paper that different detectors are better or worse depending on the fire source. However, Heskestad expands upon the reasons for poor performance, in the following statements.

" Evidently, the ionization detectors poor response to smoldering fires is intrinsic to the generic class. ... As long as characteristic lengths L do not exceed 6 ft., variations in design are not expected to greatly influence its performance in smoldering fire starts. The photoelectric smoke detector did not perform adequately in the important flaming starts,..., the large value of characteristic L (20.9-86.7 ft) is suspect. Great improvement in performance is expected in these fires if geometric redesign to values of L near 10 ft. is accomplished." (Italicization is mine.)

I would like to point out that "L", is a measure of how easily smoke enters the sensing chamber. A detector with a small "L" will have a more "open" design, thus facilitating smoke entry, as opposed to a detector with a larger "L". That is why a geometric redesign that "opens up" the detector, has the potential to lower the "L" factor and improve response.

This geometric redesign appears to have taken place just a couple of years after this study. In 1978 the National Bureau of Standards reported,

> *"Photoelectric detectors are almost exclusively using long life light-emitting diode (LED) light sources, more efficient scattering angles, and light receivers and circuit designs which minimize scattering angles, and which has been encountered in earlier LED designs. More photoelectric detectors are using electronic ambient light rejection, which eliminates the need for restrictive light-tight chambers which slow their response to fire produced aerosols.*[s10]

This redesign should have, in theory, lowered the L factor for typical photoelectric smoke detectors. This lowering of the L factor was apparently observed by a study conducted in Finland in 1992. A comparison of the different L measurement is contained in Table 6.[3']

Table 6: Smoke Detector Length Measurements[31]

	Characteristic Length (L) of Detector	
	Ionization	**Photoelectric**
1975 (Heskestad)[29]	**6** ft.	21 ft. - **86 ft.**
1992 (Finland)[31]	10 ft. - 11 ft.	8.5 ft. - 26.5 ft.

It appears that the detectors used today have different characteristics than those used by Heskestad in 1975. The increase that was measured in the L of the ionization detector may be due to the inclusion of an "insect guard" requirement into the U.L.217 Standard. This requirement states that "The maximum opening size shall not be greater than 0.05 inch." This requirement appears to have been incorporated into U.L. 217 in the late 80's.[32] It is my opinion that it is flawed logic to base testing and approval methods as well as installation guidelines on research that may be outdated due to technological changes. In the next two sections I would like to discuss this concern.

PART FOUR: MANUFACTURERS GUIDELINES AND CODE REQUIREMENTS

Manufacturers Guidelines

It is important and worthwhile to review some manufacturers recommendations and current codes to see if they take this greater susceptibility to cooking smoke, by ionization detectors into account, as well as the "smoke aging" affect.

In a manual published by one manufacturer titled "A Method For Improving Smoke Detector Codes In The United States[i33], the manufacturer recommends using photoelectric detectors in, "Existing small apartments where kitchens or open flame heaters are adjacent to sleeping area." This manufacturer also recommends using a photoelectric detector if you have to place a detector within 20 ft of a furnace or heater. This agrees with the Life Safety Code Handbook which states, "Unless the detector can be located far enough from the kitchen to avoid odors, the better choice is a photoelectric detector."["]

Another manual titled "Guide For Proper Use of System Smoke Detectors["34] recommends that you do not place detectors in the following areas:

1. In damp or excessively humid areas, or next to bathrooms with showers.
2. In or near areas where combustion particles are normally present, such as in kitchens or other areas with ovens and burners....
3. In air streams passing by or through kitchens. Air often enters a residence or a residential unit of an apartment building through cracks around the front and/or back doors. If the air return is in the bedroom hallway or in the bathroom, and if air from the kitchen easily enters the air stream going from the door to the air return, combustion particles from cooking can cause nuisance alarms."

The problem with these recommendations is that many smaller apartments and houses cannot comply with them and still meet referenced standards recommendations.

Nationally Accepted Reference Standards

As an example of this phenomena, let me compare the manufacturers guidelines to NFPA 72.[18] The example given in NFPA 72 A-2-5.2.1, is a perfect example of this inconsistency between the manufacturers recommendations and the standard's installation recommendations. The detector, indicated by a cross, seems to be within 20 feet of a kitchen and in the "air stream". It would seem that following the recommendations of these manufacturers' booklets and the LSC Handbook that the detectors illustrated in NFPA 72 should be photoelectric, due to nuisance alarms.

For Figure 5, (A) is the recommended location for the smoke detector. (B) is the most likely location of a bathroom. (In fact, in the same picture, in 17`h Edition of the NFPA Handbook this room is identified as a bathroom.

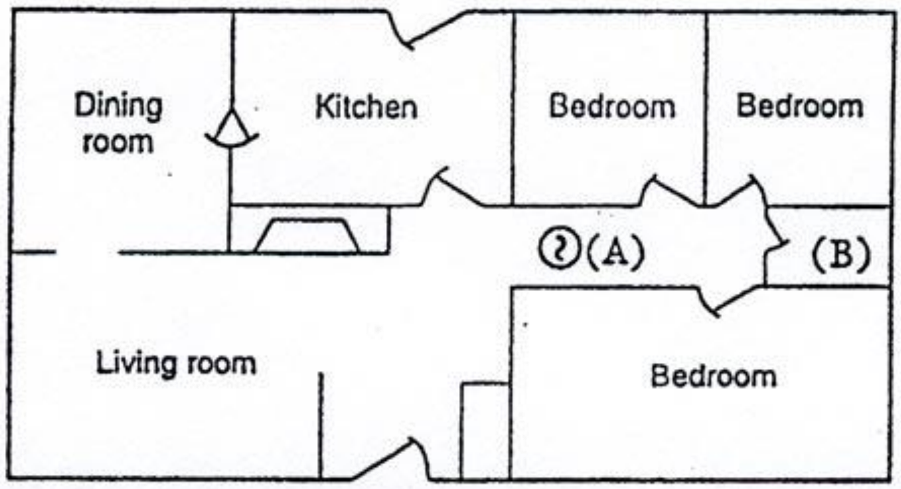

Figure 5: Recommended Detector Placement and Locations[18]

If one assumes that the living room is 9 ft. by 12 ft., then the smoke detector as indicated is approximately 5 ft from the kitchen door, 8 ft from the bathroom door, and in the air stream from the door of the apartment to the bathroom vent. On the other hand if you attempt to locate it so that it is at least 10 ft from a kitchen or bathroom, as well as out of the "air stream", you would probably have to place it near the living room, which moves it away from the sleeping area. Another concern would be a fire in the dining room. By the time the smoke from a fire, particularly a smoldering fire, reached the detector, it may be so "aged" that it causes a delay in the response. The studies cited in this paper indicate that this scenario is much more likely with an ionization detector.

This installation paradox is exacerbated by the testing and approval standards. Consumers, in my opinion, probably assume that nationally recognized testing and approval standards are screening for all-important factors in regards to a particular product. In the case of nuisance alarms, a consumer who experienced false alarms from a detector located in the location recommended by NFPA 72, would naturally assume, in my opinion, that all smoke detectors must be screened for susceptibility to the most common nuisance alarms and are therefore all equivalent in terms of their ability to avoid nuisance alarms. Based on the assumption that all detectors that pass a nationally accepted standard are "equivalent" the consumer would assume, in my opinion, that their can be no advantage of switching to a different type of detector since all detectors, that pass the nationally accepted approval standard, must behave the same way. A consumer may not even be aware that different detectors exist. I would now like to discuss the *nationally* accepted testing and approval process for smoke detectors.

PART FIVE: TESTING AND APPROVAL PROCESS

In my *opinion,* there appears to exist some inconsistencies between the manufacturers' recommendations regarding nuisance alarms and code requirements for detector location. What compounds this situation is the fact that, although false alarms from cooking appears to be the most common cause of nuisance alarms. Smoke detectors are not tested for sensitivity to invisible smoke, such as from cooking, in the approval process. Actually, many people seem to believe that U.L. does conduct a test of this type. This may be due to the fact that for smoke detectors that are to be used in recreational vehicles, U.L. 217, Standard for Single and Multiple Station Smoke Detectors[30], requires a "Contamination Test" for Cooking By-Products. However, it is important to point out that this is not a test to determine how sensitive a detector may be to cooking by-products. As I understand this test, it is a test to see if repeated exposure to cooking by-products changes the sensitivity of the detector.

Since the late 1980's, Underwriters Lab has tested smoke detectors for sensitivity to false alarms from smoldering smoke. Detectors are not supposed to alarm prior to an obscuration level of 0.5%/foot. This was apparently added to screen out susceptibility to false alarms from smoking.[32] But, if a test for sensitivity to smoking is warranted, is not a test for sensitivity to cooking warranted? As indicated by Table 1, the problem of nuisance alarms from cooking is at least 5 times greater than the problem of nuisance alarms from smoking.

I do not point this out solely to criticize the smoke detector approval method. It may be difficult to develop a reliable reproducible test for sensitivity to small/invisible particle smoke. I point it out because, I believe that many people assume that to be approved, a smoke detector would be tested for sensitivity to the most common source of nuisance alarms, such as small/invisible particles from cooking, the largest percentage of the problem by far. They are not. This impacts on consumer preference. It is possible that consumers are assuming that if one type of detector has a hyper-sensitivity to cooking smoke then all detectors must, since all detectors have to pass the same tests to be approved.

Another potential problem, that results from the testing and approval process, is that many people that I have talked to, assume that the number on the back of a smoke detector that provides a smoke obscuration measurement, such as 2.0+/-0.2% obscuration/foot, gives an approximate obscuration at which the detector will operate. As an example of this let me quote a recent "performance-based design that stated the following. "Smoke detector activation was modeled using light extinction (optical density) levels. The higher the optical density, the darker the smoke (lower the visibility). For Underwriters Laboratories acceptance testing of smoke detectors, a minimum sensitivity based on optical density is 0.06 OD/m, (4% obscuration per ft.) for gray smoke. ... Any smoke detectors that are installed as a result of this analysis shall have an activation threshold of at least 0.06 OD/m (4% obscuration per ft.)[35]

Actually this number is obtained during a sensitivity/calibration test. In the U.L. 217[30] test, the smoke detector is placed in a "smoke" box 6ft x 1.5ft x 1.5 ft and smoke is blown toward the smoke detector by a fan. Another test is run later on in the testing process where the smoke detector is placed in a room on the ceiling and walls 17.7 feet away from the fire. The detectors are subjected to 4 sources of smoke and have to detect the smoke within a certain time frame. The four tests are summarized below.

Table 6: Summary of UL 217 Fire Tests

Test Number	**Combustible**	**Detector Must Respond** Within	**Maximum Obscuration Allowed**	**Time of Maximum Obscuration**
A	1.5 oz Shredded Newsprint*	4 min.	28 %	100 sec.
B	6 x 6 2.5 in. Layered Fir Woodstrips*	4 min.	12 %	160 sec.
C	30 ml Regular Leaded Gasoline*	3 min.	14 %	180 sec.
D	1 oz Foam Polystyrene-Type Packing Material*	2 min.	13 %	70 sec.
E	Ponderosa Pine Sticks Over Hotplate**	70 min.	10 %	N/A

*** Flaming Fire**
**** Smoldering Fire**

Clearly it seems possible that smoke detectors are being approved in such a way that even in the room of origin they may not operate until well beyond 4% or even 10% smoke obscuration. (I do not mean to indicate that they will not activate at 4% or 10 %. I only want to point out that they are not guaranteed to go off at 4% and 10%.)

This situation is exacerbated when one considers that most smoke detectors in the United States are located in hallways, which are outside the room of origin, leading to even further delays. These delays are due, not only to the fact that it takes time for the smoke to reach the detector, but also to the agglomeration of the smoke. If the smoke has agglomerated then the average particle size will be larger, leading to a decrease in sensitivity, particularly for ionization detectors. I do not mean to imply that detectors that pass the U.L. test do not go off until the maximum obscuration that exists during the test.

I do mean to imply that, without any documentation that indicates the % obscuration that the detectors do activate at in realistic conditions, I have no guarantee that they might not go off at the maximum, or even higher.

This concern is illustrated in the results obtained by the IAFC subcommittee discussed earlier. The subcommittee recommended that chiefs conduct their own tests involving smoldering fires, because they believed that:

> *"This test will show that most photoelectric detectors, operated by battery, will detect the smoke at about 1 1/2 to 3% smoke, which is good. The test will show that the photoelectric detectors, operated by household current, will activate between 2 and 4%, which is still good. But, the test also will show that many ionization detectors will not activate until the smoke obscuration reaches 10, 15, 16, 17, 20, and sometimes 25%.*[s37]

The IAFC subcommittee also expressed concern about the U.L. test. They stated, "The fire service is told continually that a UL label identifies the 'good' detectors. Surprisingly enough, at present (i.e. 1980), Underwriters Laboratories only tests detectors under scientifically repeatable conditions which do not necessarily indicate how the detector performs under actual fire conditions."

The reasons for the selection of White Pine as the material to be utilized in the smoldering smoke test are outlined in a 1979 article by Harpe and Christian.[38] They state that,

> *"In order to produce a first generation test method in a reasonable time period, consideration was limited to a single class of material. The choice of that material was aided by the fact that among many combinations of materials commonly used in upholstery and bedding, cotton fabric and padding seem to be the most easily ignited in the smoldering mode by cigarettes. Accordingly, the test development was based on smoldering fires in cotton mattresses."*

These researchers found that ponderosa pine sticks gave off the type of smoke characteristics that most nearly resembled the smoke characteristics of the smoldering cotton mattress fires. Unfortunately, this "first generation" smoldering test became the "only generation" smoldering test, at least for smoke detector approvals. If it is appropriate to test multiple materials in the flaming mode, isn't appropriate to test multiple materials in the smoldering mode?

Another study[39] measured the actual obscuration that caused smoke detectors to go into alarm, during smoldering fires, and compared that number to the number on the back of the detector. Tests were performed in a sealed room measuring 12 feet by 11 feet with an 8 foot ceiling, to simulate a small bedroom. Materials burned included Douglas Fir, as originally proposed, and white pine, as later adopted in UL 217, as well as common households throw pillows consisting of 65% polyester, 35% dacron, and 4% cotton, and a standard urethane mattress with synthetic cotton covering.

Table 7 clearly illustrates several important points.

1. The sensitivity rating on the back of the detector is not necessarily indicative of the obscuration level that the detector will activate at in a real fire.
2. The photo-electric detector appears to respond much closer to the sensitivity level listed on the detector than the ionization detector.
3. The only material that, on average, alarmed the photoelectric detector below 10% obscuration was White Pine. This is important since White Pine is the material that is used during the smoldering fire test by Underwriters Laboratories where the detector must activate before 10% obscuration. If it is the smoldering fire that kills most people at night it seems critical that we test at least as many different types of items during the smoldering test that we use during the flaming test.

Table 7: Smoke Box Sensitivity vs. Smoldering Room Fire Sensitivity "

Table A. Alarm Points					
Type	**Smoke** Box Sensitivity (%/ft.)	Test #5A- **Douglas** Fir (%/ft.)	Test #11B White **Pine** (%/ft.)	Test #18D **Urethane** (%/ft.)	Test **#16A Polyester** Pillow (%/ft.)
Ionization	L1	(A/P not recorded)	7.4	21.6	
Ionization	1.78	15.6	10.4	N/A	26.8
Photoelectric	1.68	.85	1.2	.5	1.0
Ionization	.85	7.7	6.2	20.0	N/A
Ionization	-	10.7	10.6	N/A	N/A
Ionization	3.7	18.0	9.6	N/A	28.4
Photoelectric	1.5	1.6	1.3	3.6	2.8
Ionization	1.3	11.2	8.9	20.0	21.8
Ionization	-	18.9	11.0	N/A	33.0
Ionization	4.0	N/A	N/A	N/A	N/A
Photoelectric	1.23	2.2	1.4	6.5	6.8
Ionization	-	7.2	4.8	18.8	12.1
Average Ionization	2.2	14	8*	20	25
Average Photoelectric	1.5	1.5	1.3	3.3	3.4

- Identifies item selected for moldering smoke test

N/A Indicates "no response."

The reason for using White Pine appears to have been to copy the type of smoke given off by the most common smoldering scenario of the 1970's. However, it appears that an unintended consequence was that a material was picked, white pine, which allows ionization detectors to more easily pass the smoldering smoke test. While I recognize the need of using only one material due to the fact that the researchers were trying to develop a test in time for adoption into the new U.L. 217 Standard, which was adopted in 1979. I do not understand why nothing has been done to improve the smoldering smoke test in the last 20 years. It seems clear that the sensitivity of the ionization detector to some items, in particular plastics, may not be well represented by its response to White Pine. Yet, most people assume that the U.L. testis an adequate measure of a detector's ability to alert occupants to all kinds of smoldering fires.

The ionization's detector decreased sensitivity to plastic fires was apparently observed by two other reasearchers4° "Detector sensitivities were factory pre-set so that alarm would result at approximately 2%/ft smoke obscuration for punk smoke generated at 1.5 +- 0.2percent per foot per minute." Some of the results are listed below.

> *"Generating smoke at 1.25 +- 0.25%/ft-min at a low velocity of 40 ft/min caused detectors to respond at obscuration levels of 2%/ft for punk smoke (with a 40% Relative Humidity(RH)) but for PVC line cord insulation. The detectors responded at obscuration levels 9%/ft (at 28% RH) and 12%/ft (at 46% RH). Higher smoke generation rates (5%/ft-min) result in alarm at obscuration levels of 10.5%/ft for polyurethane foam, (23% RH), 15%/ft for PVC (at 28%RH) and 17.5%/ft for PVC(at 46% RH). At 100ft/min air*

velocity, alarm levels are 2% for punk, 10% for polyurethane, 17% for PVC, and 19% for polyethylene."

The authors also measured the typical particle size of the smoke given off by different materials. They concluded that,

"Summarizing for all conditions of smoke generation rate and relative humidity, ionization type smoke detectors show overall sensitivity, based upon percent smoke obscuration per foot at alarm, in order punk > polyurethane > polyethylene > PVC. Smokes prepared by pyrolysing under comparable conditions of smoke generation rate and relative humidity show increasing mass median diameter in the order punk < polyurethane < polyethylene < PVC. This indicates that ionization detector sensitivity is a particle size dependent phenomenon for various pyrolitic and smoldering combustion sources."

In a letter to the editor published in the same volume, Dick BuKowski[41] pointed out the following:

"The decreasing sensitivity (increased alarm point) obtained by Welker and Wagner for the different smokes is caused by decreasing number concentration rather than increasing mean particle diameter."

This phenomenon was discussed earlier in this paper. It is raised again here to point out the potential inapplicability of testing a detector's sensitivity to smoldering smoke with only one material. If ionization detectors have a decreased sensitivity to plastic materials, then a test that only measures sensitivity to "white pine" may not be adequate. The U.L. test does not seem to provide a good indication of a detector's ability to detect a smoldering fire in a room adjacent to the detector when plastic material is involved. Yet this is not an unreasonable scenario to protect against. In fact, according to the NFPA Handbook, manufactured fabric is involved in 36% of the fires and 42% of the civilian fire deaths.[42]

Actually, a series of smoldering fires, utilizing materials other than white pine was developed for use in a recent series of fire tests that utilized the same test facility used to test smoke detectors. The purpose of the tests was to develop temperature and gas generation data from smoldering or burning materials in their early stages of fire growth (i.e. well ventilated fires) along with traditional measurement of smoke obscuration so that they may be used in the development of multi-point detection systems. The items that were burnt in the smoldering mode were polystyrene pellets, 100% cotton, plywood, PU foam, bread slices, and red oak.[43] If it is technically feasible to develop multiple smoldering smoke tests, as this paper seems to suggest then it does not seem unreasonable to test smoke detectors to multiple items as part of the approval process. To provide a complete picture of a detectors ability to detect smoke multiple items should be burnt in the smoldering mode.

It is interesting to compare some of the numbers for smoke obscuration at which ionization detectors activate to some estimates for smoke obscuration which prevent egress.

Table 8: Recommended Tenability Limits

Author	Tenability Limits for Egress	
	% Obscuration/foot	OD/m
Babrauskas[44]	30	0.5
Jin (unfamiliar with	4	.06
Jin (familiar with location)"	13.5	.2
Newman and Kahn[06]	6	.09
Cote[25]	17	.265

Apparently many experts feel that egress is difficult if not impossible at obscuration levels that are below some of the maximum obscuration level allowed during the UL Flaming Fire Sensitivity Tests. For the most part, they are above the 10% allowed by U.L. for the smoldering tests. But they appear to be below many of the obscuration levels measured by for smoldering fires, particularly when plastics are involved. This information implies that detectors may not activate in time if they activate at obscuration levels above 10%. This conclusion appears to be supported by charts generated by Harpe and Christian[38] from data collected at Indiana Dunes. They compared the "Estimated Success Frequency vs. the "Detector Response Sensitivity". Success was defined as detector activation 2 minutes or more before zero warning time. (Zero warning time was defined as the first occurrence of untenability on any primary escape route.) When the detector was located on the same level as the fire then the detector's success rate was: approximately 95% successful detection if it activated at 10% obscuration per foot, approximately 70% successful detection if it activated at 15% obscuration per foot, and approximately 50% successful detection if it activated at 20% obscuration per foot.

I recognize that the obscuration level at the ceiling will reach untenable levels before the obscuration level at breathing height does, but based on my experience at actual fires, while "waiting for the water", when the smoke generation is such that these levels of obscuration are being reached at the ceiling the fire is in the part of the fire growth curve where the slope is relatively steep. It is a very short period of time from this point in the fire until the time that the upper layer reaches breathing height. The point I am trying to make is that the margin of safety is not as large as most people assume that it is.

The problem of smoke agglomeration in combination with the fact that the testing and approval process does not seem to take this into account leads to the possibility that many fires might be going undetected until it is too late. Support for this is found in; Fire In the United States 1983-1990. "In about 15%, of the fatal fires, the detector was present and did not operate ... In about 20% of fire deaths, a detector did operate. This is somewhat disturbing since there is a widespread belief that an operating detector will save lives. In some of these cases, the detector may have gone off too late, to help the victim, the victim may have been too inebriated or feeble to react, or the fire may have been too close to the victim. Such cases merit further study.[s20]

PART SIX: COUNTER ARGUMENTS

The small number of Problem Homes

I will admit that in regards to the susceptibility to nuisance alarms that only a minority, although significant number, of homes actually become "problem homes". Some might argue that we should not regulate everyone in a way that will only benefit a small percentage of the total population. However, since it is impossible to determine ahead of time what type of occupancy will be inhabited by the buyer of a particular smoke detector all detectors should be sold as if they were going to be installed in potentially "problem homes", i.e. small apartments, locations with bedrooms off the kitchen, etc.

This logic, not only makes sense' it has been applied before in similar circumstances. Since 1973 all mattresses and pads manufactured in this country were required to pass the test in DOC FF 4-72, Flammability Standard for Mattresses. In this test, lighted cigarettes are applied to a smooth surface, tape edge, quieted location, and tufted location.[47] All bedding is regulated even though only a minority of people in this country smoke and an even smaller minority smoke in bed. Since it is impossible to determine ahead of time that will purchase the mattress, all mattresses are regulated.

Its a "location problem"

Some people might argue that better location of detectors solves the problem but for many people that is not an option. Relying on unsophisticated consumers to properly elect the correct detector and locate it correctly is not a solution that I have a lot of confidence in since I am not familiar with even many firefighters who understand the issue and very little consumer friendly information is provided prior to purchasing. In fact every salesperson that was queried gave information contrary to the information in this article.

Hard-wire the detectors

Another solution offered by some people is to hard-wire detectors. However, as I have seen all too often in my experience responding to false alarms, people will just remove the entire unit if it is experiencing a nuisance alarm problem. Hard-wiring an ionization detector in a location too near sources of nuisance alarms might actually make the situation worse since it is more difficult to remove and re-install batteries than to remove and re-install an entire unit. The possibility that hard-wiring detectors may make the problem worse might explain the following statement from Fire in the United States, concerning apartments. "Detectors were present and did not operate in 20% of deaths (30% adjusted). This is 50% higher than the rate of non-working detectors in dwellings. These statistics are unexpected as apartment detectors are more likely to be hardwired into the electrical system and professionally maintained than detectors in dwellings.[s48] This result is not unexpected if one assumes that apartments, on average, are smaller than dwellings. In fact, this would be expected if, as is likely, the detector is placed much closer to kitchens and bathrooms in apartments than in dwellings This could lead to more nuisance alarms and as a consequence, more disabling of detectors. In a recent inspection that I conducted in one high rise building-in Boston with studio apartments we found approximately 15% of the hard-wired detectors disabled in one fashion or another. Most occupants blamed nuisance alarms from cooking.

In any case, while this is a possible solution to the problem in new construction, it is not a practical solution to the problem of what to do in existing homes, where the cost of retroactively installing hard-wired detectors is prohibitive.

Its a Consumer Issue

The reason that we have to legislate this change is partly due to the fact that there appears to be a slight cost advantage in favor if the ionization detector. I am convinced, that an educated consumer would think that the minor added expense was worth it. I know I did as well as many of my friends and relatives. But educating the consumer in this matter would be difficult if not impossible. Even when I convince someone to choose photoelectric detectors they find it nearly impossible to find one on a store shelf. Consumer Reports acknowledged this in their article. They reported that, photoelectric detectors remain scarce in stores - they found only three to test and one was actually a combination detector. "Since consumers view both detectors as being equally efficient, they will always buy the lower priced detector. This has led retailers to stop carrying them.""

The free market's efficiency is proportional to the knowledge base of the consumer. Without the knowledge that the manufacturers supply to installers, how are consumers to be depended upon to make the right decision. Consumers will not have any reason to demand photoelectric detectors until they are educated. Stores will not carry photoelectric detectors on the shelf until consumers are demanding them. I would have more faith in the efficiency of the free market to deal with this issue, if the consumers had as much information as many professional installers seem to have.

Relying upon the informational booklet that is contained in a typical smoke detector package is impractical, in my opinion, for two reasons: 1) If the information is inside the box it cannot affect a consumers choice, which is made prior to opening the box, and 2) the information is not "user friendly". Based on my experience, it is not common practice, even among the firefighters that I work with, to pay strict attention to the information that is placed inside the box. I am not familiar with anyone who has read and understood all of the information in the manufacturer’s instruction prior to installing the detector.

Utilize "silence" or "hush" buttons

Some might argue that the solution to at least the nuisance arm problem is to market detector that have a "silence" button that reduces the sensitivity of the detector for a short period of time. Let me quote the authors of the study conducted the Native American Community. "Hush buttons are less than an ideal solution for at least two important reasons. First, frequent nuisance alarms from ionization detectors will still be annoying and will eventually prompt many owners to disconnect the power source. And second, owners often find it easier to remove the battery than to repeatedly push the silence button when smoke exposure is sustained, as it is during cooking.[14]

I have also seen detectors that advertised that they had a "silence" button but which in fact, utilized the "test" button as the "silence" button. While this arrangement is technically in agreement with the advertising claim, there are several practical problems. First, the button is extremely small and has to be held for 8 seconds for the "silence" feature to operate. Can it reasonably be expected that the average consumer will do this? Secondly since the button is only identified as the "silence" button in the small print of the handout that came with the detector how is anyone other than the installer supposed to know this information. If this detector is installed in an apartment, with changing tenants this feature will most likely never be used. Finally, what about the elderly or handicapped who may not have easy access to a detector placed on a ten foot high ceiling.

Restraint of trade issues

I have also heard it mentioned that by legislating one type of detector that the authority taking this step might be accused of restraining free trade and competition. But how is favoring photoelectric detectors over ionization detectors different from favoring smoke detectors over heat detectors. It is merely a question of favoring a superior technology for the environment in question.

Use Combination detectors.

Some might argue that the optimal solution is "combination detectors, i.e. detectors that contain both sensing mechanism. Several points have to be considered with this option.

1. In an "or" detector either device photo or ion will trip detector. If both devices were tested separately then we would still have the nuisance alarm problem from the ionization devices. If the devices are tested together then both detecting devices can utilize reduced sensitivity and still pass the UL test since each devices now only has to detect the type fire that it is optimally designed to detect. But for fire signatures that trip only one detection device then we could be experiencing a delay in response due to the smaller window of sensitivity.
2. In an "and" detector both devices have to "trip for the detector to alarm. This solves the nuisance alarm problem but once again causes reduced sensitivity to real fire signatures that are likely to trip one device before the other.
3. The cost and consumer supply issues that some apply to photoelectric detectors, apply even more so to combination detectors.

Points 1 and 2 are discussed more fully in an article by Reiss and Solomon.[49]

S U M M A R Y

I would like to rephrase a statement that I made at the beginning of this paper, The question that we should be answering is not,

> **"Which detector is adequately designed to detect smoke"?**

The question we should be asking is,

> **"Which detector is designed the best to detect the smoke from the type of fire from natural or manmade materials, which kills most people who are sleeping when it is located outside the room of origin and also would experience the least false alarms?"**

The answer to this question is clearly photoelectric.

For this reason, I believe that only photoelectric detectors should be recommended for residential use. As indicated earlier many sources recognize the advantage of photoelectric detectors in regards to nuisance alarms. I would now like to point out some sources, which favor photoelectric detectors, without even taking into account the issue of nuisance alarms.

Norwegian researchers[24] who concluded,

> *"In many countries like in Norway, 90-95% of the smoke detectors installed in homes are ionization types of detectors. Here, smoldering fires are often caused by smoking (ignition by a glowing cigarette) and those who have installed such detectors are satisfactorily safe providing measures are made to prevent smoldering fires from starting. This means that smoking in bed must be avoided. If such homes are to purchase new detectors, the recommendation is that the optical smoke detector is needed."*

Australian researchers[50], who concluded,

> *"An acceptable arrangement for protection against smoldering fires under the conditions investigated appears to be photoelectric smoke detectors located at each end of the hallway."*

The International Association of Fire Chiefs, who, in 1980's, concluded,

> *"Therefore, because of the present state of the art in detecting smoke, the Subcommittee on Smoke Detectors can take no other course but to recommend the installation of photoelectric detectors. The subcommittee makes this recommendation because most home fires start from a smoldering source and because the photoelectric detectors are sensitive to open flame fires as well as smoldering flames."*

> Note: I would like to point out that in a letter[s'] dated May 10. 1996 The IAFC took the following position, "Tests show that the differences in response time are small enough that both types provide enough time for escape."

> Unlike the position in 1980, the tests used to justify this opinion were not cited. The IAFC did agree in this letter that if there was a problem with nuisance alarms from cooking, "If the detector is the ionization type, another option is to replace it with photoelectric."

In reviewing hundreds of articles I have not come across any that came to the conclusion that the ionization detector is superior to the photoelectric in a residential setting.

I suspect that there are those who believe that my proposal to only allow photoelectric detectors to be used in residential occupancies is too radical. I admit that the benefit in terms of life safety is not absolute. Ionization detectors do save many people and photoelectric detectors will not save everyone. However, many of the requirements that are contained in regulations and codes offer only relative benefits over other options that are not allowed. The question should be stated in terms of whether the incremental decrease in risk is worth the incremental increase in safety. I believe without question that in this case it is. Another point that I would like to make is that most of the articles that I reference have been around for several years. As a consequence, not only is this idea not radical, it is probably many years overdue.

For those who disagree with me, I would hope that they would agree that at a minimum the following should be done.

1. Change the testing and approval process.
    - A. Those standards of smoke detector approval include a part that measures sensitivity to the most common types of nuisance alarms. If we had an assurance that ionization detectors were no more susceptible to false alarms from cooking than photoelectric detectors then we would not have to favor photoelectric for this reason.
    - B. Test detectors in a manner that measures their sensitivity to fire signatures both inside and outside the room of origin. That is, test for susceptibility to "smoke aging".
    - C. Test for sensitivity to smoldering fires from multiple sources, similar to the way they are tested for flaming fires. It is a fair assumption that a large number of fires, particularly smoldering fires involve man-made materials. Why aren't smoke detectors tested for this scenario?

2. Collect data in a different manner.

    I believe that one of the reasons that this information is not more widely known is that it is "hidden". Not being aware of the phenomena discussed in this paper investigations into fatal fire do not usually look at things such as whether the detector was in the same room, whether the type of smoke was the type that the detector in question was susceptible to. In fact, there is no place on the NFPA Incident Reporting Form; NFPA 901[50] to state which kind of detector was involved. When I have talked on this subject at conferences I have never failed to have at least on person come up and tell me that they think some of these issues may have been involved in a recent fatality in their community.

    We must collect this information on a national level. We must pinpoint why so many detectors are inoperative and why 20% of the fatalities occur when the smoke detector works. Information that must be gathered is:

- Type of detector.
- Power Condition (hard-wired or battery powered)
- Power Source Condition. (If the detector is inoperative try, to interview survivors to find out why. A useful piece of information could be - Location of detector relative to potential nuisance alarms.)
- Reason for occupant failure to respond to a detector that operated. Useful information to obtain could be:
- Location of detector, relative to fire origin. I.e. was smoke aging a factor in a delayed activation?
- Reason for occupant failure to respond to a detector that operated. Useful information to obtain could be:
    1. Was audibility a factor? Were people sleeping behind closed doors with the air conditioner on?
    2. Was the victim impaired?
    3. Was the victim intimate with the fire?
- Was the fire a "fast flaming" fire or a "smoldering" fire.
- Break down locator location in the following manner:
    1. Room of Origin (If yes did it work?)
    2. Floor of Origin (If yes did it work?)
    3. Apt. Unit of Origin (If yes did it work?)
    4. Common Area Detection (If yes did it work?)

3. Address Consumer Issues.

A. That ionization detectors have a warning placed on the front of the package that states that, "WARNING - This detector may not be suitable in locations where it has to be placed within 20 feet of a kitchen or heater with open flame".

B. Approve some detectors for any purpose and other detectors (susceptible to false alarms) as only for non-residential detectors.

C. Mandate that any detectors that do not pass a "nuisance alarm test' be equipped with a silence button, that is readily identifiable and easy to use.

4. Re-Do "Indiana Dunes""""

The testing at Indiana Dunes set the stage for several important advancements in the U.S., including the conclusion that smoke detectors are better than heat detectors and that one smoke detector per level was needed. It was also used to help justify the original design of the UL smoke detector test. However advances in smoke detector technology and changes in the approval process have reduced the relevance to the current situation. In addition to the issues discussed earlier, concerning improvements in technology and changes in materials there is a third problem with using the results from Indiana dunes to justify policy. This reason has to do with the reduction in sensitivity, which I believe exists, between the average detector today compared to the typical detector used at Indiana Dunes. In my opinion, this reduction in sensitivity stems from the changes that were incorporated into the U.L. approval process in the eighties to address the nuisance alarm problem." Some of the changes, as I understand them, were the following: 1) changing the smoke box sensitivity from 0.2% to 4% to the current 0.5% to 4%, 2) adding requirements for insect screens, and 3) adding certain test to make detectors less sensitive to atmospheric conditions such as changes in humidity and wind velocity. In order to pass the new test, it is possible that many detectors ended up with a higher sensitivity rating than the typical detector at Indiana Dunes.

In the testing at Indiana Dunes some of the detectors use had sensitivity as low as 0.61% obscuration. In fact in phase two of the testing, "a pre-set sensitivity of 1% per foot obscuration was requested from the manufacturers". [26] I have rarely come across smoke detectors in the field that are set at this low of a level. If this decrease in sensitivity did occur, it may help explain the test result that have been conducted in the last few years that find that ionization detector do not appear to adequately detect smoldering fires. Actually, this result could have been anticipated based on the testing at Indiana Dunes. One of the conclusions of Phase Ones was:

> *"Whereas detectors set at nominal 2% per foot obscuration generally provided adequate warning, those detectors whose sensitivities were near 1% per foot (actual) provided a considerable increase in escape time for smoldering fires, The effect was much smaller for flaming fires.*[s27]

This conclusion seems to predict that any decrease in the average sensitivity should cause a corresponding decrease in ability to detect fires. Particularly smoldering fires. It seems clear to me that we have to conduct an up-to-date test using today's detectors and today's materials.

Smoke detectors deserve a tremendous amount of credit for the reduction in life and property loss due to fire in the last two decades. Since most of the detectors in the United States are ionization detectors then they deserve most of the credit. In so far as the Underwriter laboratory Standard provided a minimum standard that the detectors had to meet and encouraged advances in technology it also deserves some of the credit. But, I believe that it is time to update the standards and update the testing process to recognize new technology and new information. (Of Course by "new" I am referring to just about anything that took place after the early 80's.)

I like to think of it in these terms. Phase One of the United States experience with smoke detectors seemed to be to get the cheapest possible detector, thereby maximizing usage, into as many homes as possible. Phase Two should be to get the most cost-effective, not the cheapest, detector into as many homes as possible, with all new construction being hard-wired and battery back-up. The history of Fire Safety in the United States has been a gradual and continual progress in technology and code requirements, why should the residential detector be different

I would appreciate it if anyone has any information on any study, fire, etc. that would support or oppose the position taken in this paper that it be sent to me at the following address:

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